Blue and Fin Whale Habitat Modeling from Long-Term Year-Round Passive Acoustic Data from the Southern California Bight

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LONG-TERM GOALS

During this project, we developed predictive, year-round habitat models of the presence of calling blue and fin whales in the Southern California Bight (SCB), to facilitate Navy's operational needs in this area.

OBJECTIVES

The primary objective of this research was to develop predictive, year-round habitat models of the presence of calling blue and fin whales in the Southern California Bight (SCB). We also investigated the scales over which blue and fin whales respond to their environment to better understand the functionality of the predictive relationships in those models. The models were based on the available passive acoustic and remotely sensed data available for the SCB.

APPROACH

Passive acoustic data have been collected using High-frequency Acoustic Recording Packages (HARPs) deployed at sixteen locations in the SCB (Figure 1). We used automatic detectors to determine the presence of blue and fin whale calls in the area of the SCB between 32° and 34° 20' N from passive acoustic recordings collected year-round between 2006 and 2012 (Širović et al., 2015). This temporally extensive data set allowed us to investigate the effects of environmental, remotely sensed variables, as well as a number of temporal variables, such as month, season, and year, on the distribution of these two species of whales. Such temporal variables are rarely included into models based exclusively on visual survey data thus our models offered new insights on the importance of these time scales on blue and fin whale habitat preferences.

Environmental variables obtained from remotely sensed data used for habitat modeling included sea surface temperature (SST), sea surface height anomaly (SSH), chlorophyll *a* concentration (Chla), and primary productivity (PP). These data are available on similar temporal (weekly, monthly) and spatial scales (1 to hundreds of km) as passive acoustic whale recordings. Data that are contemporaneous spatially and temporally for each deployment location and period were downloaded using the *Tethys*

database tools developed by M. Roch (ONR grant N000141110697). Additional variables tested for inclusion included weather buoy data (e.g. wave height, wind) collected through the National Data Buoy Center for the parts of the SCB region with HARP deployments, however they were not selected in the final models.

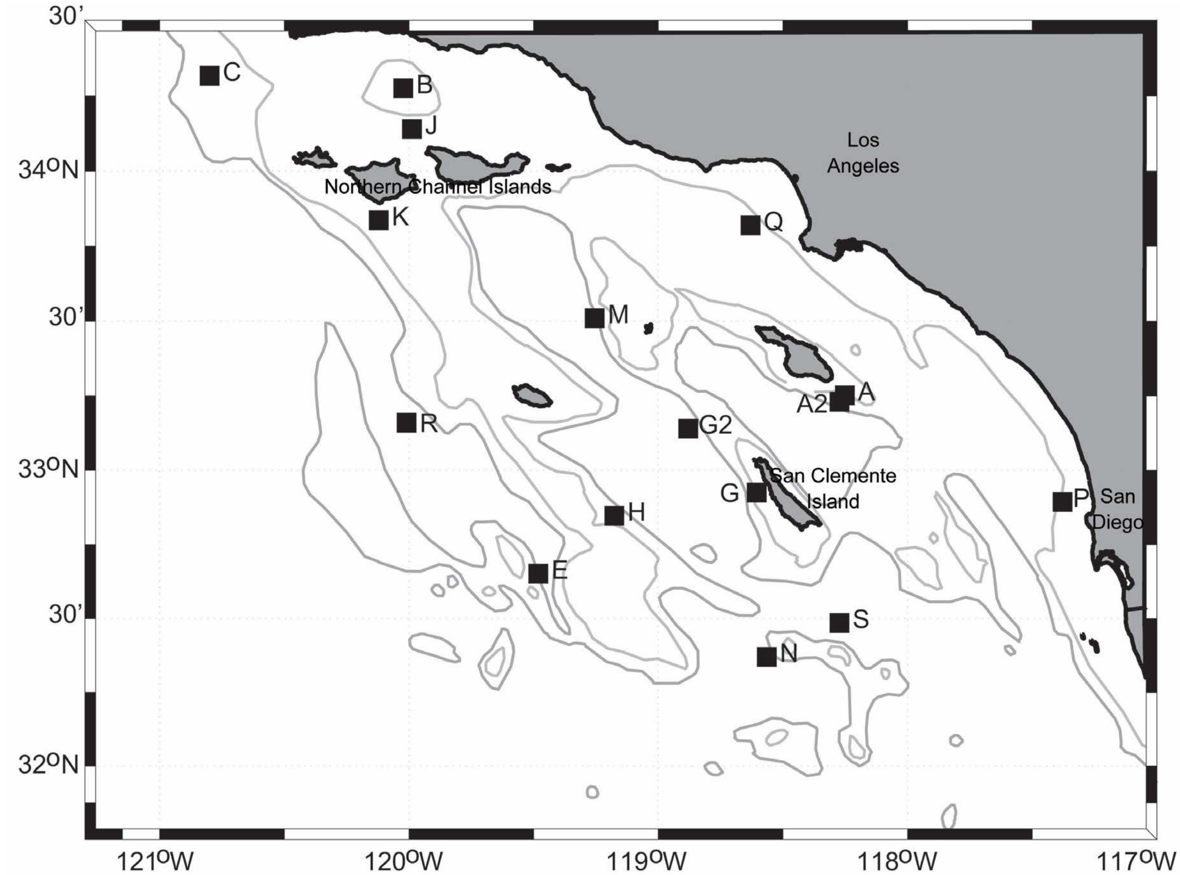

Figure 1. Sixteen HARP deployment locations (black squares) throughout the Southern California Bight between 2005 and 2012 from which data were processed for habitat modeling in this study. Light grey line denotes the 500 m bathymetry contour.

When comparing acoustic and remotely sensed data, and for meaningful habitat modeling, one of the major problems is determining the appropriate spatial scale on which to conduct the analysis. On the one hand, the choice of scale is limited by the spatial resolution in collected data, but in theory, it should also be driven by the scale of the whale's response to the environment. We explored the effect of different spatial scales on blue and fin whale habitat models. To use call detections for such an analysis, however, we first must determine the scale (range) over which whale calls can be detected. Using ESME workbench (developed under ONR grants to Dr. Mountain), we developed propagation models for areas around each of the HARP deployment locations to investigate the characteristics of propagation loss in the area. These models allowed us to estimate propagation loss at low frequencies over different spatial scales and over different seasons (spring, summer, fall, and winter). They also allowed for close coupling between passive acoustic and environmental data, enabling us to investigate the effects of range on the functional models affecting blue and fin whale distribution.

First, all data were spatially and temporally aligned to compare the presence of blue and fin whale calls with the environmental variables. Next, we used random forest framework to identify the variables that should be used for subsequent modeling. Independent environmental variables that were used for selection in the models includes: SST, SSH, Chla, PP, and when available wave height and wind speed. Generalized additive modeling (GAM) framework was used subsequently to describe the functional relationships between calling abundance of these whales in the SCB and important environmental variables. We built single-site and meso-scale models (defined as areas of high and low abundances of individual species' calls), as well as seasonal models, and tested the predictive abilities of the models. The advantage of this method over the habitat models that have been developed from more traditional ship-based visual surveys is that passive acoustic data provide a much finer and also longer temporal resolution.

The metadata for all detected calls (location, time, and type of call) and, to the maximum extent practicable, our final, best habitat models have been formatted for incorporation into the Ocean Biogeographic Information System – Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) database for access by the larger community.

WORK COMPLETED

- Analyzed 26 instrument-years of data for presence of blue whale and fin whale calls from the SCB.
- Integrated all passive acoustic detection metadata into the *Tethys* database and formatted for inclusion to OBIS-SEAMAP. (We will finalize inclusion to OBIS-SEAMPA once the final manuscript has been accepted for publication.)
- Extracted all spatially and temporally collocated environmental data needed for habitat models.
- Built explanatory models for single sites, as well as areas of high and low abundances of blue and fin whale calls.
- Built seasonal models for areas of high and low abundances.
- Tested predictive abilities of developed models.
- Revised and resubmitted manuscript on the temporal variation in the performance of automatic spectrogram correlation detector for peer-review (Širović, under review).
- Published manuscript on 7 years of blue and fin whale presence in the SCB (Širović et al., 2015).
- Prepared manuscript on blue and fin whale habitat models from passive acoustic data in the SCB for peer-review.

RESULTS

Over 3 million blue whale calls were detected at 16 sites during 9,404 days (nearly 26 cumulative years) of effort, although some calls may have been detected on more than one instrument. Blue whale B calls were generally detected between June and January, with a peak in September (Figure 2). Across the years, there was some variability in detection numbers, with a slight peak in 2008, and minima in 2006 and 2007 (Figure 2). Fin whale acoustic index, indicative of the 20 Hz calls, was

highest between September and December, with a peak in November (Figure 2). There was a secondary, smaller peak in fin whale acoustic index in March. Across the years of this study, there appears to be an overall increase in fin whale acoustic index (Figure 2, red line)

Generally, sites around the northern Channel Islands, particularly to the north in the Santa Barbara Channel, had the highest call abundances during peak calling periods, but blue whale B calls were also common along coastal sites near Los Angeles and San Diego (Figure 3). There may be a preference for Channel Island sites earlier in the calling season, while later in the season call distribution is more even across the SCB. These differences were used to define areas of high and low preference for blue whales for the habitat modeling portion of the work; areas within 20 km or less from shore or one of the Channel Islands were defined as high, while the rest were classified as low abundance.

There was also a seasonal cycle in the fin whale acoustic index (Figure 2), coupled with a large amount of spatial variability across the SCB (Figure 4). Peak in the fin whale acoustic index occurred during fall, with a broad shoulder and a secondary peak in the winter and a minimum during June and July. Fin whale acoustic index was the highest farther offshore and farther south during peak calling periods (Figure 4) than was the case for blue whale call detections, with highest levels in the basin just to the west of San Clemente Island. Geographically, thus, areas of high fin whale abundance was defined as locations between latitudes of 32° 32’ and 33° 22’ N, while sites outside that region were classified as having low fin whale calling abundance for the purposes of habitat modeling.

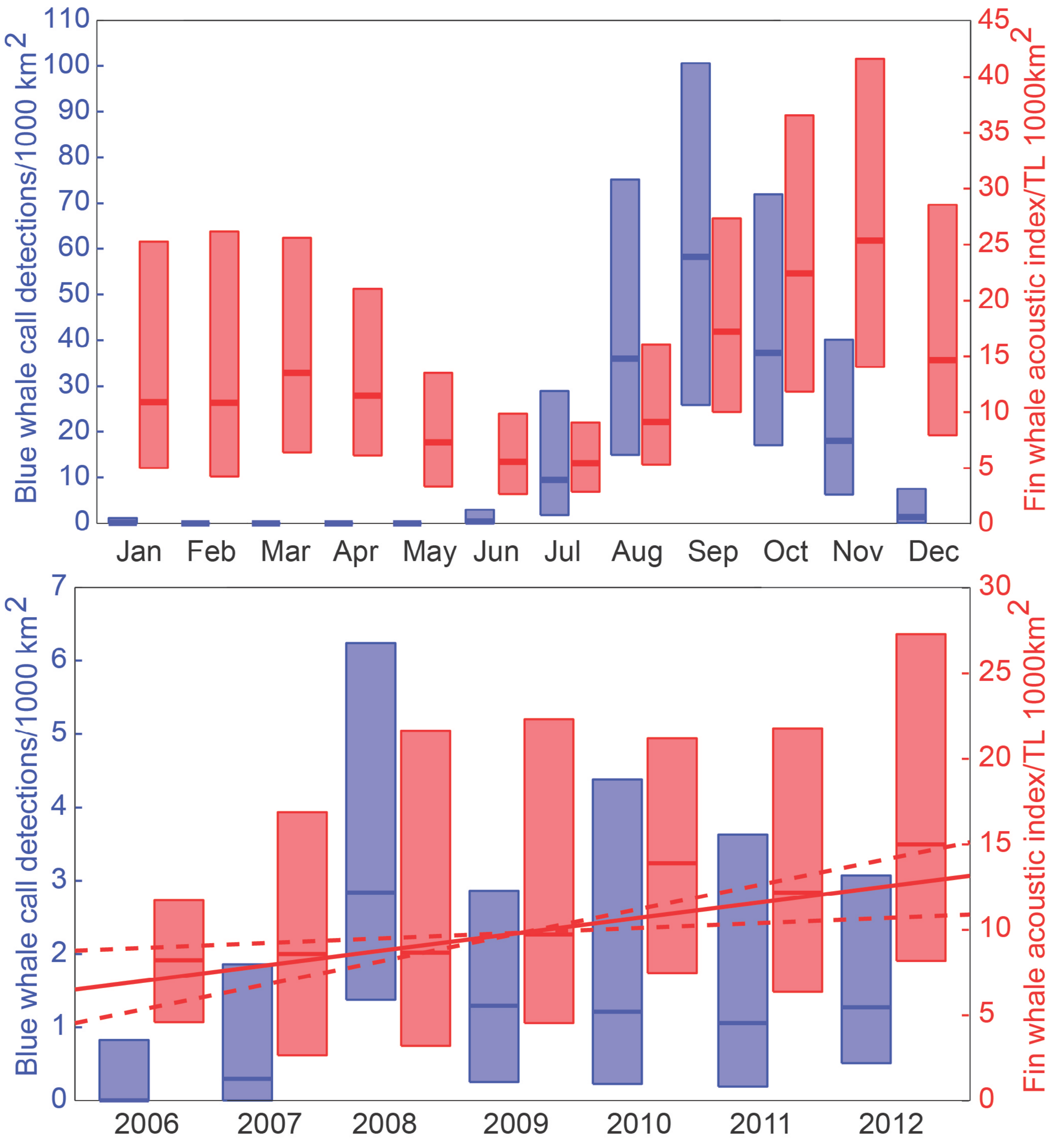

Figure 2. Overall monthly seasonal (top) and yearly interannual (bottom) trends of blue whale B call daily detections normalized by detection area (blue bars) and daily fin whale acoustic index normalized by detection area and transmission loss, TL (red bars). Red lines show Sen's slope (solid line) with 95% confidence intervals (broken lines) for interannual trend in fin whale acoustic index over the years.

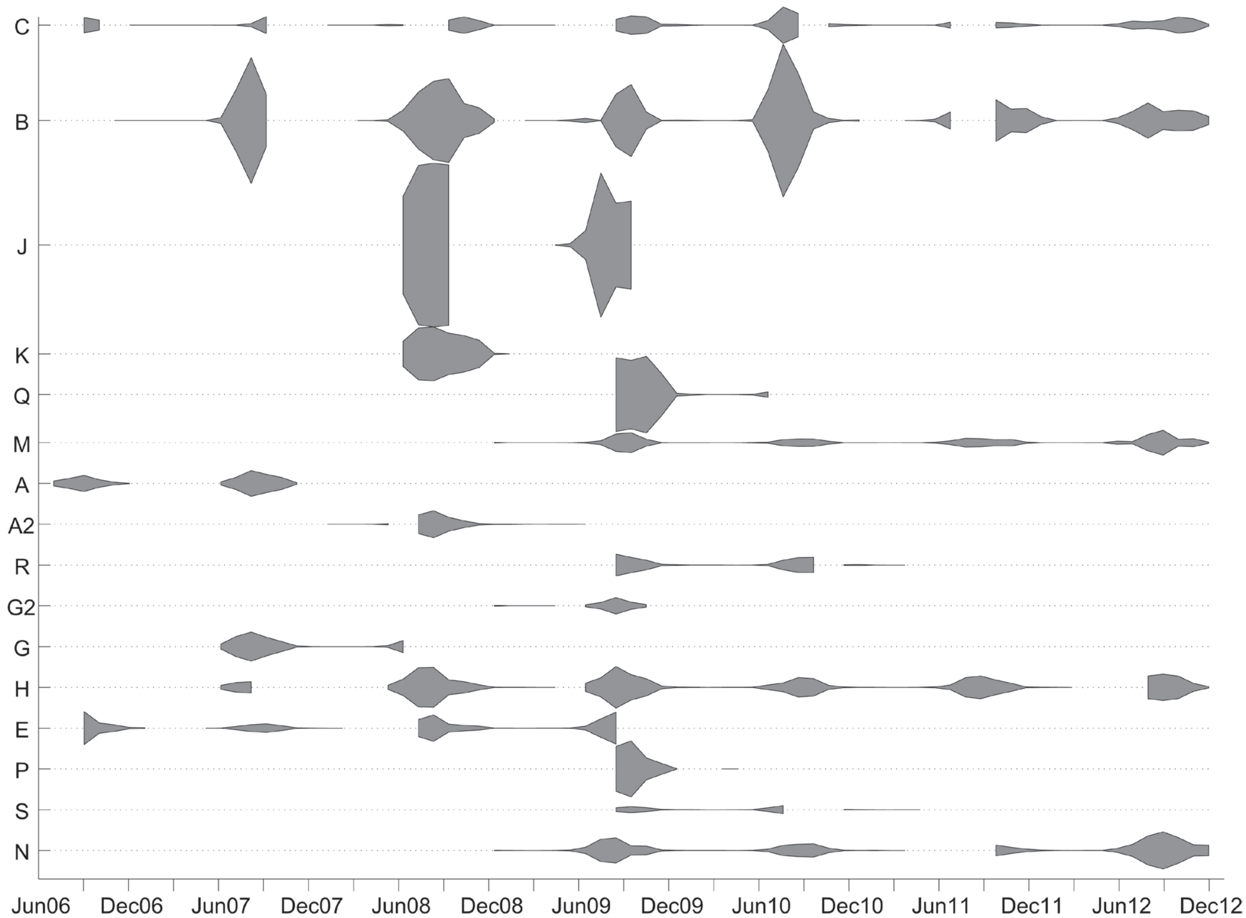

Figure 3. Monthly averaged daily blue whale B call detection rates at each site in the SCB. Sites are arranged, to the maximum extent possible, from the northernmost sites at the top towards the southernmost sites at the bottom. Size of the patch represents the daily call detection rate normalized by the modeled detection area. Dotted lines are periods with no data at that site and straight lines denote periods with recording but no detected calls.

Overall, the developed GAMs were better at explaining the deviance in blue whale call detections than the fin whale acoustic index (Table 1). For both high and low areas of detections, month, SST, and sea surface height anomaly were the variables with the most explanatory significance for blue whale B calls (Figure 5). Interestingly, the direction of the relationship with the SSH anomaly changed between the high and low area, and in areas with low abundance, chlorophyll a concentration was also a significant explanatory variable. For fin whale acoustic index habitat models, month, sea surface height anomaly, and primary productivity were significant explanatory variables, and additionally SST was a significant variable for high abundance habitat model (Figure 6). Unlike blue whale calling, that either had positive or negative relationship with SST depending on the calling abundance region, there was an optimal SST for peak fin whale acoustic index. However, SST was not an important explanatory variable in areas of low abundance. Functional relationships for SSH and PP changed between the two areas, also, from a negative relationship to a largely positive response to increase in the independent variable (Figure 6). Interestingly, for fin whale seasonal models, month became less important variable and most seasonal models did not include month as a significant explanatory variable, but in blue whale seasonal models month persisted as an important variable (Table 1).

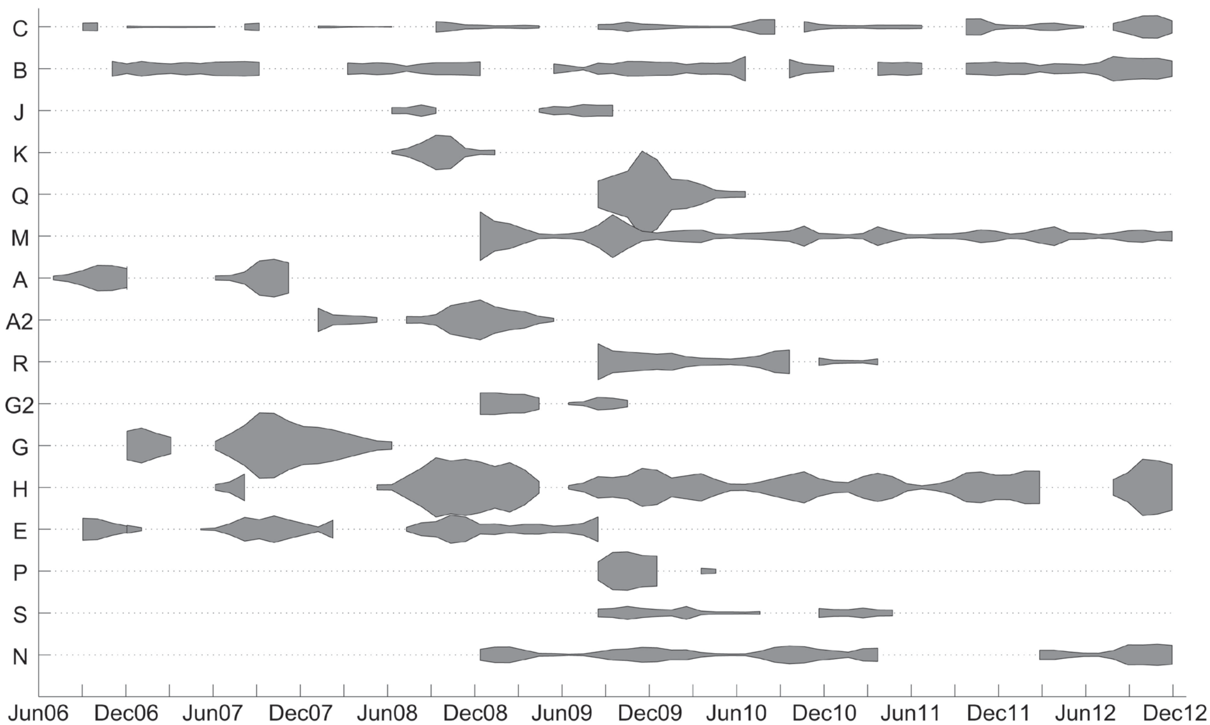

Figure 4. Monthly averaged daily fin whale acoustic index at each site in the SCB. Sites are arranged, to the maximum extent possible, from the northernmost sites at the top towards the southernmost sites at the bottom. Size of the patch represents the acoustic index value with periods that appear as straight lines denoting low fin index acoustic index value. Dotted lines are periods with no data at that site.

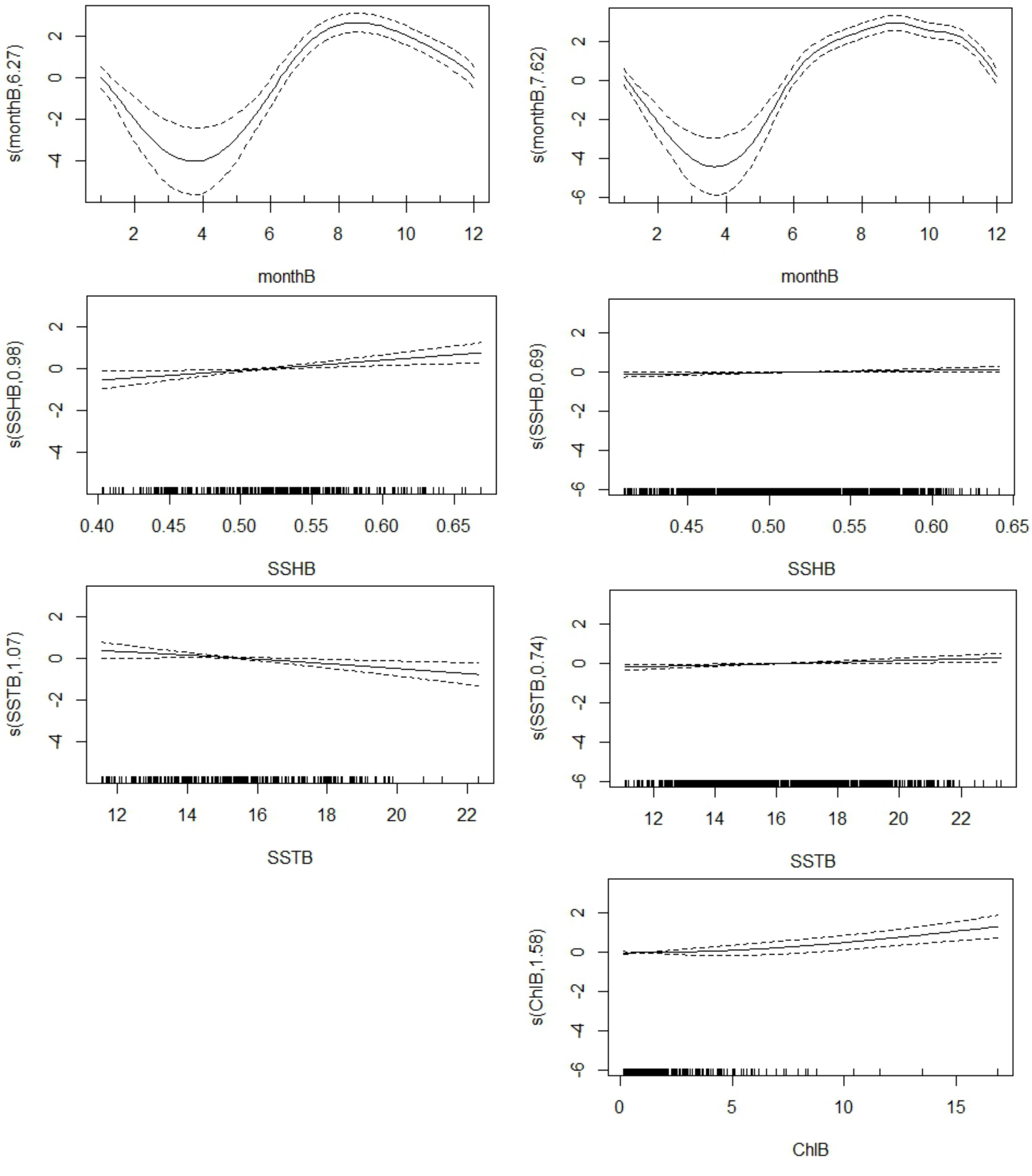

Figure 5. The mean-adjusted partial fit of each significant predictor variable for the best blue whale B call detection rate model for areas of high (left) and low (right) calling abundance. Higher values on the y-axis indicate more whale detections. The plots show the average of the partial fit (solid line) and the standard error of the fit (dash-dot line). The vertical lines along the x-axis indicate the number of observations at each value of the predictor variable.

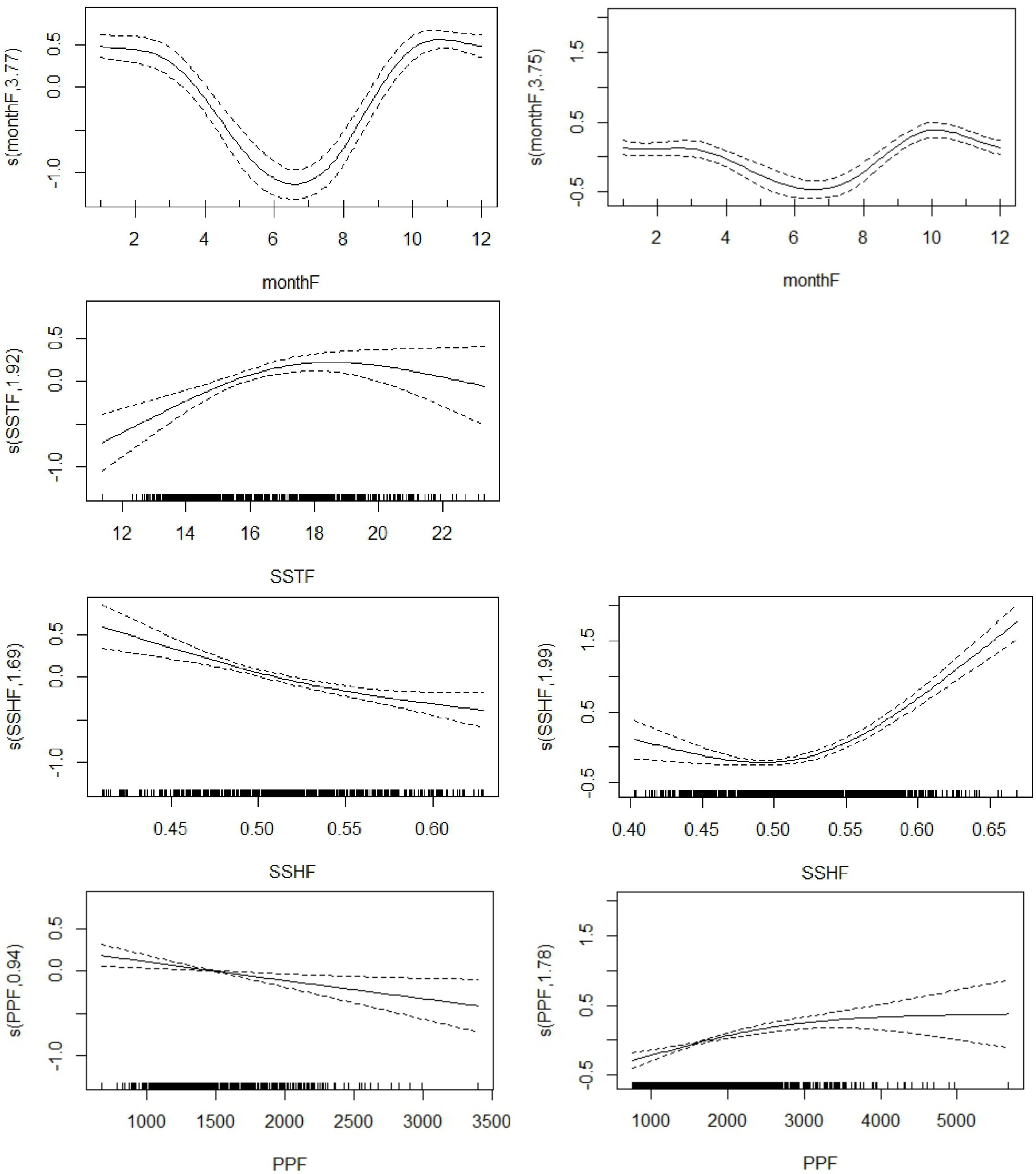

Figure 6. The mean-adjusted partial fit of each significant predictor variable for the best fin whale acoustic index model for areas of high (left) and low (right) calling abundance. Lines and values are the same as described for Figure 5.

When testing year-to-year predictive abilities of the models, we found that generally the models performed well in predicting overall trends, but were less reliable in predicting the magnitude of the response variable.

Table 1. Selected variables and general model performance statistics for the different habitat models of calling blue and fin whales, broken down by areas of high and low abundance, and including different seasonal models for each area. Note that no winter models were developed for blue whales as there were generally very few calls in the winter. Likewise, low abundance fin whale summer time models could not be developed because the sample size of the response variable was too small.

Model type	*Selected variables*	*N*	*GCV score*	*Deviance explained*
Blue whale: high full	Month, SST, SSH	304	44.172	69.1 %
- Spring	Month, year, SSH, PP	81	1.706	88.2 %
- Summer	Month, SST, SSH, PP	81	91.92	33.4 %
- Fall	Month, SSH	87	51.633	36.1%
Blue whale: low full	Month, SST, Chla, PP, SSH	1041	7.417	74.9 %
- Spring	Month, SST, PP	243	1.467	62.1 %
- Summer	Month, PP, Chla, SSH	256	15.08	38.6%
- Fall	Month	260	10.379	43.8%
Fin whale: high full	Month, SST, SSH, PP	511	8.047	39.3 %
- Spring	Month, SST, Chla	82	4.560	50.2 %
- Summer	Month, PP	103	5.364	45.9 %
- Fall	SSH, year, SST	105	459.35	23.2 %
- Winter	SSH	98	312.18	13.9 %
Fin whale: low full	Month, SSH, PP	789	5.938	32.8 %
- Spring	PP, SST	239	4.240	13.6 %
- Summer	-	-	-	-
- Fall	SST, SSH	229	4.884	21.9 %
- Winter	SST, SSH	235	5.247	20.6 %

IMPACT/APPLICATIONS

Understanding the distribution of cetaceans over space and time is relevant for the Navy's operational needs in Southern California. Unlike visual observations that generally provide limited temporal resolution, passive acoustic methods have the potential to resolve changes in the distribution of marine mammals on both short and long-term temporal scales. Therefore, passive acoustic methods have the potential to be used to improve our understanding of the dynamics of habitat use and population distributions of vocalizing cetaceans. The spatially-explicit habitat models for calling blue and fin whales developed during this project will enhance the ability of the Navy to predict blue and fin whale occurrence in the SCB region year-round and their incorporation to the OBIS-SEAMAP environment will improve their utility for other users.

RELATED PROJECTS

During this project, we used the *Tethys* database (http://tethys.sdsu.edu) developed under the project "Acoustic metadata management and transparent access to networked oceanographic data sets" (ONR

grant N000141110697, PI: M. Roch) for data management as well as easy access to oceanographic data needed for habitat modeling. We also used the ESME workbench (esme.bu.edu/index.shtml) for propagation modeling at sites in the SCB (ONR grants N0001411C0448, N000141210390, N000141310641, PI: D. Mountain). The results of this project have also highlighted the need for additional data collection and funding awarded under a recent DURIP grant (award 1000002072 to PI Širović) will help further refine habitat models by incorporating prey into similar analyses.

PUBLICATIONS

Širović, A, A Rice, E Chou, SM Wiggins, JA Hildebrand, MA Roch. 2015. Seven years of blue and fin whale call abundance in Southern California. Endangered Species Research, 28: 61-76.

Širović A. (Under review) Variability in the performance of the spectrogram correlation detector for Northeast Pacific blue whale calls. *Bioacoustics*.